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System Start-up and Thaw in Space

The SP-100 space reactor power system (SRPS), shown in Figure 1, uses molten lithium as a heat transfer fluid. The molten lithium is pumped through the reactor, where it is heated to 1375°K, and then transported through a primary piping loop to the thermoelectric power conversion assembly (PCA) which converts a portion of the heat to electrical energy. A secondary piping loop employs molten lithium at a nominal lower temperature of 850°K to cool the PCA and provide the temperature differential across the thermoelectric converter elements needed to generate electrical energy. The secondary piping loop transports the heat removed from the PCA to heat pipe radiators, which reject this heat to space by radiation.

Lithium is solid until it reaches a temperature of 450°K. For nominal ambient temperatures of less than 300°K encountered during launch, lithium will be in the frozen or solid state. This is advantageous for ease of handling and safety during launch. The reactor and transport loops will be filled on the ground and then allowed to cool until the lithium is frozen. After launch, the frozen lithium must be thawed as part of the start-up sequence.

During freeze-up, the molten lithium contracts and forms zones with voids as well as regions of solid

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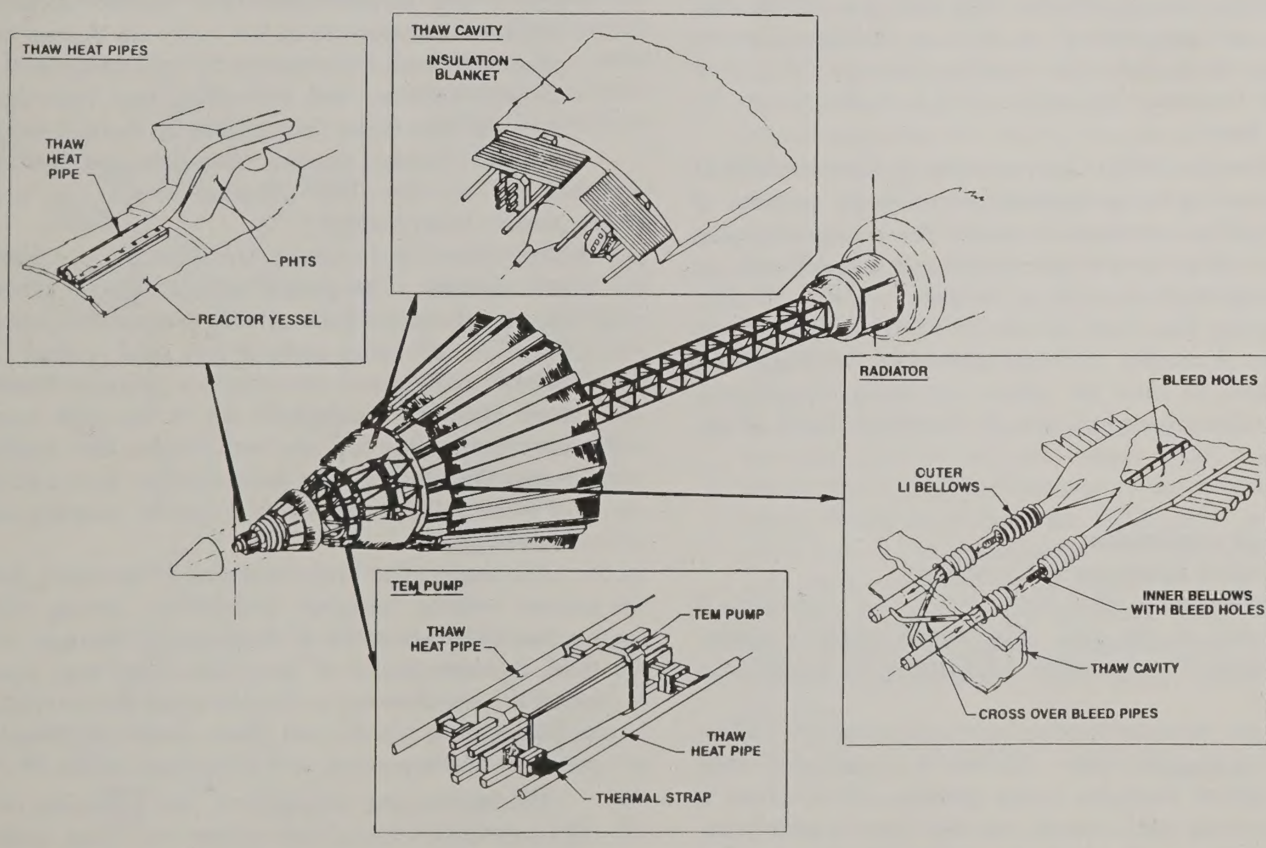

Figure 1 — SP-100 Space Reactor Power System

System Start-up and Thaw

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lithium within the reactor and transport loops. If a region of solid lithium is heated during thaw, it tends to expand and exert forces on the reactor vessel, piping, pumps, and PCA. Experience with ground-based liquid metal systems has shown that these forces can induce stresses of sufficient magnitude to damage these components. Thus, the system must be thawed in a manner that keeps expansion-induced stress levels within the design limits of the affected components.

Ground-based liquid metal pumped loops have been thawed successfully by an approach that involves

System start-up in space depends on thawing the frozen liquid metal working fluid contained within the complex geometrical boundaries of the reactor and network of primary and secondary transport loops.

the initiation of thaw at a void or gas-to-solid interface. As the solid liquid metal at the interface expands and becomes molten, it flows into the void or gas zone, thereby relieving stresses. The void size and heating rate are determined so that a melt-front moves progressively from the interface through the system while the expanding molten fluid is displaced into the void zone.

For the SRPS, this proven progressive melt-front approach is being implemented on major portions of the system, particularly within the transport piping loops. The current reference design is predicated on starting the reactor in a low-power mode and then using the heat from the reactor to thaw the transport loops. A number of design approaches for using reactor heat to thaw the system are being investigated. One of the concepts is described below in terms of key steps.

Launch Preparation — Controlled Freeze-up on the Ground

- The reactor is filled and frozen so that a void zone is located at one end. The void is sized to accommodate the expansion of lithium in the reactor vessel.
- A gas separator/accumulator is used because helium is generated when lithium is bombarded with neutrons from the fission process. This helium is removed and stored in the gas separator/accumulator. The gas separator/accumulator is filled and frozen with a helium bubble implanted in its center. The helium quantity is selected to give the desired pressure level in the reactor and primary loop when the system is thawed.
- The thermoelectric electro-magnetic pumps (TEM) and sections of the attached piping are frozen with implanted void zones.

System Start-up — Controlled Thaw in Space

- The reactor is started with a controlled power ramp-up rate to keep stresses within established limits.
- Thaw heat pipes attached to the reactor vessel supply heat generated in the reactor core to the primary heat transport loop (PHTS) that includes the inlet and outlet piping of the reactor. As the heat pipes thaw, they transfer heat to the PHTS and thereby sustain a melt-front that moves progressively from the reactor through the piping.
- The TEM pumps are attached to the thaw heat pipes via thermal straps. These straps provide the added heat needed for pump thaw and startup.
- The thaw cavity is an insulated zone containing transport system components between the TEM pumps and bellows connection to the deployed radiator. Components in the cavity are thawed in a progressive melt-front manner by implanting voids in selected locations and controlling heat rates from the thaw heat pipes through use of thermal straps, radiative coatings, thermal insulation, and positioning of the thaw heat pipes relative to the components being thawed.
- The bellows and radiator are thawed via a bleed-hole concept. The pumps circulate molten lithium through the bleed holes so that heat extracted from the PCA and pump assembly are used to thaw the bellows and radiator assembly in a progressive melt-front manner. The bellows are thawed with cross-over bleed pipes that are small flexible lines located inside the bellows. The radiator ducts have a series of bleed holes in the wall between the outgoing and incoming flows.

The engineering implementation of the above thaw system involves complex interactions among fluid mechanic characteristics of voids during freeze-up and thaw, thermal control of heat rates from heat pipes, which are also thawing, and stress-strain characteristics of lithium as it freezes and thaws inside the complex geometry of components such as the reactor and PCA.

The engineering development and validation of a reference design for a thaw system are being undertaken in the current Ground Engineering System phase of the SP-100 Project. •

Pumps For SP-100*

In the current SP-100 system design, the primary heat transport subsystem (PHTS) and the heat rejection subsystem (HRSS) jointly employ twelve thermoelectric electromagnetic (TEM) pumps to circulate the liquid metal working fluid (lithium) within both subsystems. Unlike the massive and bulky electromagnetic pumps widely used for industrial liquid metal applications, space systems require a lightweight, compact pump design that needs no external power source. Hence, the TEM pump is a d-c conduction pump with an electrically induced magnetic field. A thermoelectric material (SiGe/GaP), utilizing the thermal gradient between the primary and secondary coolant ducts, provides the electric power and eliminates the need for an external power supply.

The operating principle of the TEM pump, the Faraday principle, was first discovered in 1832 by M. Faraday and W. Ritchie.

From the Faraday principle, we know that a Lorentz force is generated perpendicular in two dimensions to both an electric current and a magnetic field. This Lorentz force, in turn, produces pressure within the conducting fluid.

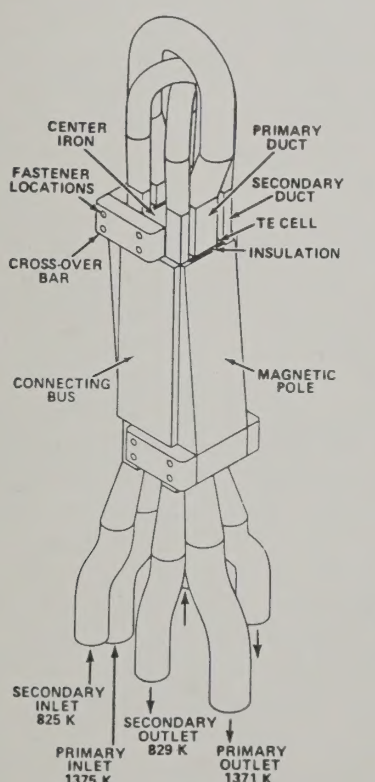

Figure 2 — TEM Pump

The configuration of the TEM pump assembly chosen for SP-100 is shown in Figure 2. Pumping for both the PHTS and HRSS are accomplished within the same device. TE cells are arranged between the primary and secondary ducts and provide a voltage source for the pump. The voltage produced is a function of the temperature difference across the TE material. The ducts and magnetic structure are configured such that the TE current induces a magnetic field in the magnetic structure. The magnetic structure directs the magnetic flux through the lithium perpendicular to the TE current in order to develop the maximum pumping pressure. Figure 3 demonstrates the direction of the current and magnetic flux through the lithium, and the direction of the flow that is produced. This pump design will operate autonomously as long as a temperature difference exists between the primary and secondary coolant loops. Also, by virtue of the temperature dependence of the voltage produced by the TE cells, the pump is self-regulating.

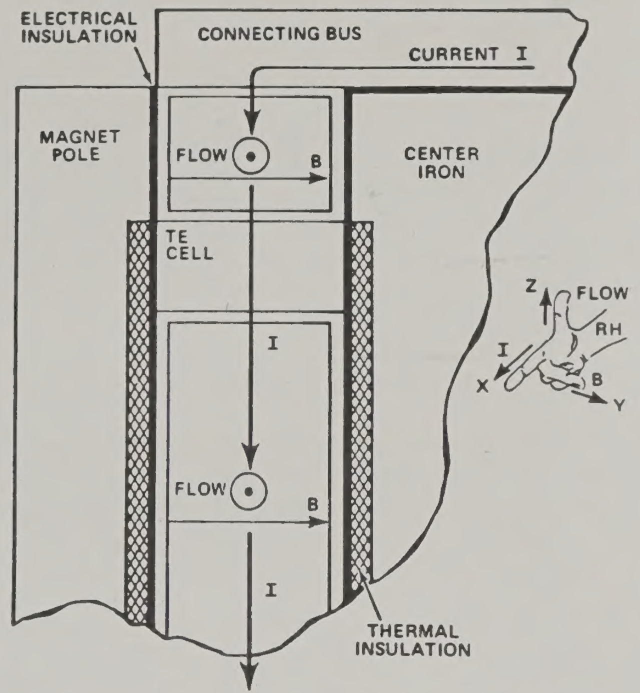

Figure 3 — TEM Pump Cross Section Detail

Of course, within the current pump design, there are numerous factors and assumptions which may impact the final mass and performance of the pump. Thus, a pump development program is in place to address these factors and assumptions. The development testing activities will include investigation of the following TE cell design magnetic structure design advanced materials and fabrication processes; electromagnetic pumping performance; and TEM pump performance. •

* Diagrams and text taken largely from Collett, J.M., "Thermoelectric Electromagnetic Pump Design for SP-100", submitted to the IECEC–ASME Advancement of Energy Technology conference held 31 July to 5 August 1988 in Denver, CO.

Los Alamos Qualifies Fuel For SP-100

Los Alamos National Laboratory has begun to fabricate fuel for the Ground Engineering System test of the SP-100 Space Nuclear Reactor. Following an extensive evaluation in December 1987, an independent technical review panel approved the Laboratory processes to produce uranium nitride (UN) fuel for the Nuclear Assembly Test (NAT).

The UN fabrication process consists of synthesis of UN powders from available uranium dioxide feedstocks followed by conventional cold pressing and sintering into fuel pellets. After the sintering, the pellets are centerless ground and inspected for QA release. The problems of escalating a laboratory fuel fabrication process to a pilot plant operation represents the culmination of three years of developing large batch operations. In January, Los Alamos began fabrication of the uranium nitride fuel pellets that will be encapsulated into fuel pins and shipped to the NA test site at Hanford.

As of August 1988 more than 10,000 fuel pellets have been fabricated, representing about 15% of the core inventory.

To ensure the smooth transfer of this technology, three representatives from industry have joined the staff at Los Alamos. The expertise they gain will expedite transfer of knowledge and techniques to private industry for production of future reactor cores. •

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High Temperature Insulator Development

To insulate the thermoelectric elements which convert heat to electricity from the hot and cold side heat exchangers require electrical insulators. The insulator must not only electrically isolate the thermoelectric cell, but be chemically compatible with its surroundings, maintain mechanical integrity, be a good thermal conductor and operate for a period of 10 years at a temperature of 1325°K with an electric potential of 100vdc across it. The demanding requirements need considerable experimentation to develop the data base for this component.

No significant degradation of sapphire insulators will occur over the SP-100 seven year mission lifetime.

Initial technology development work was performed by General Atomic, Inc. (GA) prior to the award of the SP-100 System Contract to General Electric Co. (GE). An extensive survey of the literature and experts in the field arrived in a list of candidate materials; alumina being the leading candidate. Based on theoretical hypothesis and supported by some experimental evidence[1], ionic transport was developed to be a key failure mechanism for polycrystalline alumina. Electrolytic degradation in polycrystalline alumina was evidenced in void migration to the positive electrode and aluminum to the negative electrode.

Single crystal alumina (Sapphire), which also underwent early testing, showed more stable behavior, and the development of this material became increasingly important. Short term accelerated screening tests were initiated at GE's Corporate Research & Development Center (CR&D) at temperatures of up to 1575°K. The electrical stability of these Sapphire samples is excellent, as is their extremely low electrical conductance. Initial post test evaluation of samples operating at 1575°K shows only very small alteration in microstructure. Extrapolation of the current data to the SP-100 operational temperatures of 1325°K using a physical model of mass transport, indicates no significant degradation of Sapphire insulators will occur over the required seven years of operation. •

1 – "Thermal Stability Testing of an Electrically Loaded Sheath Insulator", J. Chin, et.al., Gulf General Atomic, October 7, 1969 (GA-9465)